U.S. Army TRADOC Analysis Center
Naval Postgraduate School
Monterey, CA 93943

TRAC-MONTEREY

ANNUAL REPORT

of the

U.S. ARMY TRADOC ANALYSIS CENTER MONTEREY

For

FISCAL YEAR 2003

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Director, TRAC-Monterey
Monterey, California

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Director, TRAC
Fort Leavenworth, Kansas

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TRAC-Monterey

Mission

TRAC-Monterey serves as the principal research activity for the U.S. Army Training and Doctrine Command Analysis Center (TRAC). Its mission is to perform relevant and credible exploratory and applied research to support the TRAC mission. Research topics are broad in nature. Appropriate research topics meet the TRAC director's criteria of being a high return on investment, a benefit to the soldier, and presentable at analytic conferences and in applicable journals.

TRAC-Monterey is located at the Naval Postgraduate School and allies itself with several of the departments, including Operations Research, Mathematics, and Computer Science, as well as the MOVES Institute. TRAC-Monterey's research program offers NPS faculty and students a broad range of opportunities for studying challenging, applied problems that support NPS curricula and enhance professional development. The research program supports students from all branches of military service by providing them opportunities to investigate a wide range of interdisciplinary issues. TRAC-Monterey's research program is particularly well suited to military officers who wish to apply concepts studied in the classroom to real-world military problems.

Organization and Facilities

TRAC Headquarters is located at Fort Leavenworth, Kansas. TRAC-Monterey is one of four analysis centers organized under TRAC Headquarters. The other centers shown in Figure 1 are: TRAC-Fort Leavenworth, Kansas (TRAC-FLVN); TRAC-White Sands Missile Range, New Mexico (TRAC-WSMR); and TRAC-Fort Lee, Virginia (TRAC-LEE).

TRAC-Monterey is located in building 245 of the Naval Postgraduate School in Monterey, California. Facilities include a combat simulation laboratory, contractor and student work areas, and a modern network of computers and peripherals.

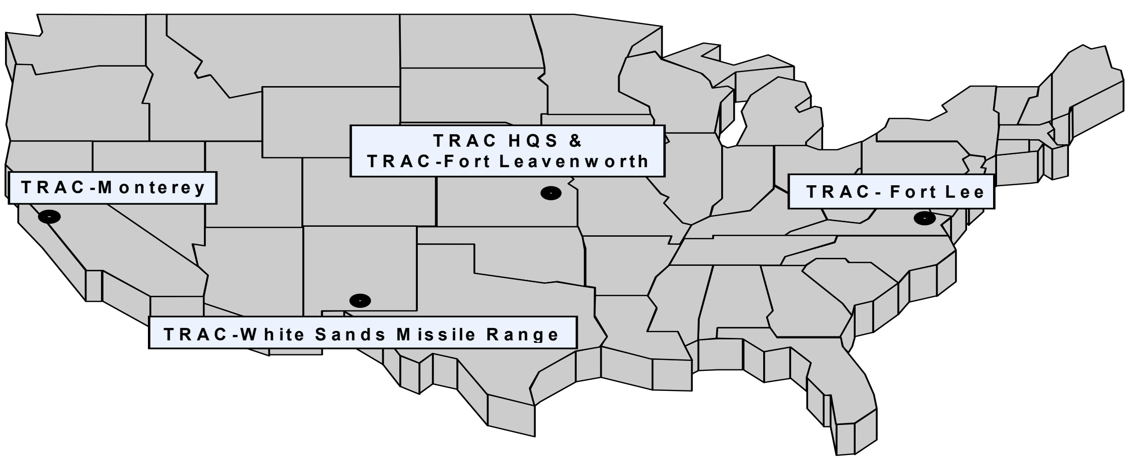

Figure 1: U.S. Army TRADOC Analysis Center (TRAC) Sites

Personnel
The TRAC-Monterey Table of Distribution and Allowances (TDA) authorizes a director (O5), a civilian deputy (GS-14), five military operations research analysts (O4/O3), and an administrative staff. TRAC-Monterey hosts liaisons from the United States Marine Corps (USMC) and the United States Army Engineer Research and Development Center (ERDC). Table 1 lists TRAC-Monterey personnel.

POSITION	NAME	PHONE (C: 831-656-xxxx; DSN 756-xxxx)	EMAIL
Director	LTC Thomas M. Cioppa, Ph.D.	3088	Tom.cioppa@trac.nps.navy.mil
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Analyst	MAJ Matthew Chesney	7575	Matt.chesney@trac.nps.navy.mil
Analyst	MAJ John Willis	7580	John.willis@trac.nps.navy.mil
Analyst	MAJ Donovan Phillips	7574	Donovan.phillips@trac.nps.navy.mil
Analyst	MAJ Nick Wittwer	3732	Nick.wittwer@trac.nps.navy-mil
USMC Liaison	Maj Lloyd Brown	7578	Lloyd.brown@trac.nps.navy.mil
ERDC Liaison	Dr. Niki Goerger	3571	Niki.goerger@trac.nps.navy.mil
TSM Soldier Liaison	SFC Chris Augustine	4059	augustic@trac.nps.navy.mil
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System Administrator	SGT Bradley Turner	7576	Bradley.Turner@trac.nps.navy.mil
Administrative Assistant	Ms. Sandra Lackey	3086	Sandra.lackey@trac.nps.navy.mil

Table 1: TRAC-Monterey Analysts

TRAC-Monterey analysts identify research opportunities, write research proposals, solicit funding and support, write statements of work for contractor and professor support, collaborate with professors, students and contractors, and lead small research teams.

TRAC-Monterey augments its organic research capability in various ways. A major source of support comes from NPS faculty members who conduct TRAC-sponsored research. A second source is NPS Masters students who work on TRAC-sponsored projects and who are advised by NPS faculty and TRAC-Monterey analysts. TRAC-Monterey also partners with other TRAC centers and other government organizations. Finally, private contractors provide software development support and assistance with proof-of-principle demonstrations.

Research Focus

TRAC-Monterey conducts research into three broad areas, identified as research pillars by the Director, TRAC-Monterey: Military Operations in Urban Terrain (MOUT) Modeling and Simulation (M&S); Elements of Combat Power; and Advancements in Simulations.

The Director of TRAC-Monterey serves as the Army-wide coordinator of the MOUT Focus Area Collaborative Team (MOUT FACT). His responsibilities include publishing a coordinated research plan, evaluating proposed research for MOUT M&S, and providing a coordinated recommendation to Army decision makers for MOUT research funding. These responsibilities necessitate an in-house workforce knowledgeable about MOUT related issues. TRAC-Monterey analysts and liaisons represent TRAC, TRADOC, and other Army interests in conferences and symposia related to MOUT M&S issues.

The Elements of Combat Power Pillar has as its origins the five elements of combat power from FM 3.0: Maneuver, Firepower, Protection, Leadership, and Information. These elements form the basis for a wide range of military operations research and are key to Army transformation principles. TRAC-Monterey research under this pillar supports ongoing Future Force and Future Combat System analyses, some of which are in partnership with TRAC's other elements.

The Advancements in Simulations Pillar focuses on transforming existing, new, and developmental simulations with technologies or techniques that will potentially revolutionize Army modeling capabilities. Under this pillar, operations research analysts perform multifaceted functions such as systems design, systems integration, and technology research that cross many functional areas. TRAC-Monterey maintains close ties with organizations that have ongoing simulation development efforts, specifically the combat developers and material developers of OneSAF and Combat^{XXI}.

Purpose of the Annual Report

The Annual Report describes the manner in which the Annual Research Plan was executed. The report provides a project status at the end of the fiscal year and a list of presentations and publications associated with the project. The Annual Report serves as a means of announcing TRAC-Monterey's research accomplishments to other TRAC centers, NPS faculty and students, and various within and outside of the Department of Defense.

MOUT Modeling and Simulation

Military Operations in Urban Terrain Focus Area Collaborative Team (MOUT FACT)

Sponsoring Agency:
Army Modeling and Simulation Office (AMSO), Attn: Mr. Dell Lunceford, 1111 Jefferson Davis Hwy Crystal Gateway North, Suite 503E Arlington, VA 22202, (703) 601-0005, wendell.lunceford@hqda.army.mil

Problem Statement:
The US Military's involvement in urban operations has escalated significantly over the past several years. Though modeling and simulation (M&S) has played a large role in the development and refinement of Army tactics, techniques and procedures, research into MOUT representations is fragmented and inadequately resourced. Core physical models are judged to be insufficient as a foundation for simulation of urban operations. To combat the deficiencies, AMSO formed a FACT. The MOUT FACT directs all future urban operations modeling efforts, ensuring that new simulations credibly depict military operations in urban terrain. Coordinated, coherent Army research for urban M&S resides in three main areas: Physical models, Terrain, and Behaviors. The overall purpose of the FACT is to ensure that a prioritized plan of research for urban M&S is formulated, documented and published.

Technical Approach:
The MOUT FACT process is a top-down approach to prioritize and address deficiencies, and identify collaboration opportunities. The goal is to promote shared, collaborative research from credible sources and eliminate duplicate efforts. Each research task will result in a demonstrable product with explicitly defined data requirements. The MOUT FACT produces two major products: a coherent research plan and a prioritized list of projects to be funded based on that plan.

The MOUT FACT uses a four-stage process (see Figure 1 below).

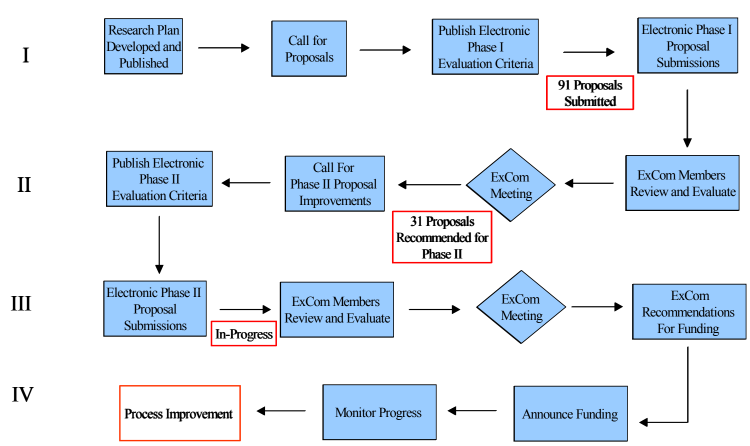

Figure 1: MOUT FACT Methodology Highlighting the Four Major Stages

The first stage is identification and assessment of urban M&S areas requiring improvement. Within each area, specific subtopics or needs are identified. Once the MOUT FACT identifies the requirements it queries the community to submit proposals that address these requirements. A web-based management system is used to accept and evaluate proposals.

During the second stage each member of the ExCom is assigned a set of proposals to review. AdCom members also review proposals and provide their professional judgment to the voting ExCom members. Evaluation criteria focus on the critical issues of Army/US Marine Corps/Department of Defense relevance, feasibility of approach, technology transfer, supportability of data requirements, risk, reasonableness of timeline, and return on investment. The ExCom uses analysis techniques including statistical cluster analysis to achieve a consensus on proposals to consider. The ExCom voting process yields a list of projects for the next phase. The ExCom then provides feedback to proposing agencies to improve proposals, identifies possible collaboration between agencies, and provides directions for further literature review.

In the third stage agencies submit refined proposals that the ExCom and AdCom review and then meet to produce a final prioritized list. This list is cross-walked against the research areas and subtopics to ensure there is a coherent linkage to the requirements.

In the fourth stage the MOUT FACT presents the prioritized list and research plan to senior decision-makers responsible for funding. Once funding is identified, the MOUT FACT monitors the progress of the projects to ensure milestones are satisfied and the deliverables match the original proposal.

Requirements and Milestones:
Announce funded projects (1Q03)
Develop management plans (1Q03)
Project funding received (2Q03)
Implementation Meeting I (3Q03)
Submission of prioritized projects list for FY04 (4Q03)
Implementation Meeting II (1Q04)

Products and Deliverables:
MOUT M&S Research and Management Plan
MOUT FACT website
Prioritized list of MOUT M&S proposals

Points of Contact:
LTC Thomas M. Cioppa, TRAC-Monterey, P.O. Box 8695, Monterey, CA 93943. 831-656-3088 (DSN 756-3088), FAX 831-656-3084, tom.cioppa@trac.nps.navy.mil

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Success Criteria:
The first element defining success for this project is the identification and prioritization of shortfalls in the representation of urban warfare and its associated environments in both legacy and emerging models and simulations. Second is the employment of an effective web-based proposal management system that permits both the submission and evaluation of urban M&S project proposals. Next is the creation of a ranked list of recommended projects for funding based on the objective evaluation of a qualified field of experts. Finally is the development of an effective project management and oversight system.

References:
https://www.moutfact.army.mil

Status:
During FY 03, eight funded MOUT FACT projects produced experimental data, algorithms, and other products for integration into emerging M&S packages (e.g. OneSAF and COMBAT^{XXI}). The eight projects were:

- Footprint to Pathfinder: Integration of Urban Characterization, Munitions Effects, and Threat Assessment for Movement Planning in Urban Environments
- Enhancement of Mobility Modeling Suite to Predict Vehicle Performance Over Roads Degraded by Urban Debris and Cratering
- Rapid Generation of Synthetic Urban Environments and Infrastructure for Modeling and Simulation Applications
- Modeling Target Loss in MOUT using Graphs
- AMSAA MOUT Radio Frequency Propagation Model
- Weapons Effects in Urban Terrain
- Development of a Human Centered Target Acquisition and Engagement Methodology
- MOUT Search in the Infrared and Visible

Seven of these projects are two-year efforts and will compete for FY04 funding.

In addition, a technical report entitled "Research Plan Development for Modeling and Simulation of Military Operations in Urban Terrain" (TRAC-M-TR-03-012) was published in March 2003.

Presentations:
INFORMS National Meeting, San Jose, CA, Nov 02
Spring SIW, Orlando, FL, Apr 03
Urban ISR Conference, Washington, DC, May 03
71st MORSS, Quantico, VA, Jun 03

Footprint to Pathfinder

Sponsoring Agency:
Army Modeling and Simulation Office (AMSO), Attn: Mr. Dell Lunceford, 1111 Jefferson Davis Hwy Crystal Gateway North, Suite 503E Arlington, VA 22202, (703) 601-0005, wendell.lunceford@hqda.army.mil.

Army G3 Director of Analysis and CIO, Attn: Mr. Vern Bettencourt, Room 3A474, 102 Army Pentagon, Washington, DC 20310-0102, Vernon.Bettencourt@us.army.mil.

Problem Statement:
The US Army is being deployed throughout the world and is operating in new and sometimes adverse urban settings. This trend is likely to continue into the foreseeable future, and the urban environment will remain a likely area of operations for the Current and Future Forces. Maneuver units must be capable of negotiating obstacles in urban environments while accomplishing operational objectives. Maneuver will be central to entering the fight on our terms, seizing objectives, and finishing rapidly and decisively. To facilitate assessment of advanced concepts, doctrine, force structure, and materiel alternatives, emerging models and simulations (M&S) will need to portray these environments. Representation in M&S of environment, munitions effects, mobility, and routing in rubblized urban areas is generally inadequate for current MOUT analysis, acquisition, and training and is the focus of this research.

Technical Approach:
Project objectives are to characterize geo-typical urban footprints; produce algorithms to depict and assess structural damage caused by conventional weapons attack; describe vehicle mobility through rubblized environments; and develop ground vehicle routing routines that consider the risks of potential threats in the urban environment.

The approach involves seven major thrust areas, each producing fundamental algorithms and products needed for portrayal of MOUT in M&S: urban footprint characterization, structural damage footprint characterization, urban mobility algorithms, engineer effort and operations algorithms, network generation and bypass algorithms, pathfinder algorithms, and architecture/integration into M&S (COMBAT^{XXI}). Algorithms will be incorporated into Application Programmer Interfaces (APIs) using COMBAT^{XXI} as a demonstration platform. Figure 2 below shows a schematic of the F2P API product integration with the host application(s).

The scope of this project includes ground vehicles based on representatives from the standard vehicle bins identified in the standard mobility API, aggregated urban templates based on Urban Terrain Zone classification, dynamic conditions for rubble generation, rubble produced from an extended set of weapons and craters, air blast impacts, targets located outside buildings, and basic obstacle descriptions based on standard non-deformable and deformable objects. The work is linked with the OneSAF Objective System (OOS) Environmental Data Model (EDM).

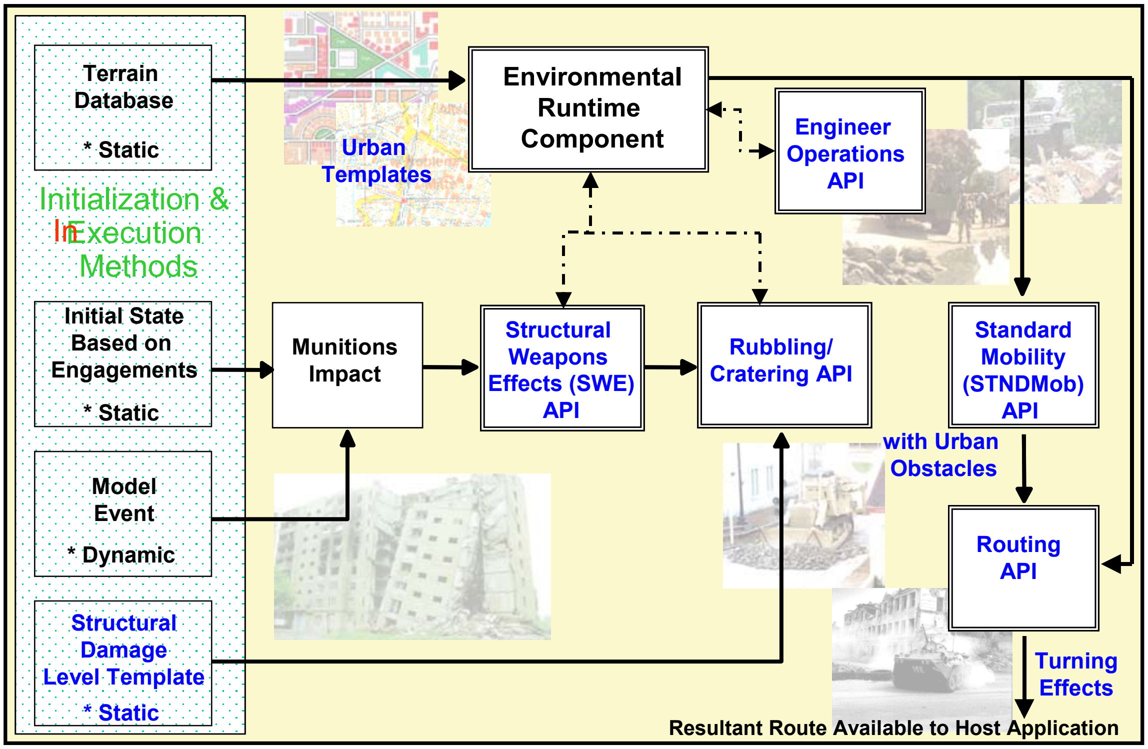

Figure 2: F2P API Product Integration

The structural damage assessment model will predict damage and associated debris from a conventional weapons attack. Algorithms will be developed for the damage assessment of typical structural types and construction materials (e.g., concrete) subjected to a limited set of conventional weapons. The algorithms will be developed based on structural response calculations and experimental data. Probabilistic algorithms quantifying rubble from structural debris will be developed based on structural response to weapon effects. The algorithm developments will directly feed into the mobility models for maneuver over structural debris and rubble in urban terrain and for damage assessment simulation models of fixed facilities on the battlefield including urban areas.

Urban mobility algorithms will be based on the NATO Reference Mobility Model (NRMM) and the Standard Mobility (STNDMob) API derived from NRMM. The obstacle crossing model and algorithms will be modified to account for rubble and craters and will be linked to the OOS EDM features and attributes. Moreover, information from the structural weapons effects API and algorithms will be cross-walked with the obstacle and crater descriptions. The result will be an extension of the STNDMob API. These results will be fed into the pathfinder model.

The engineer effort and operations algorithms will be developed in year two of the project and will provide further realism to the MOUT environment, allowing for obstacle clearing and reduction along routes. Information from the Engineer Model Improvement Program will be utilized along with field data and other work rate modifier calculations. The associated API will be available to the host application for planning and execution calls.

The engineer effort and operations algorithms, the structural weapons effects rubble and crater determination, and the urban footprint and vehicle mobility are all factors used to determine whether a vehicle can cross or bypass an obstructed area. To account for bypass, algorithms will be developed and linked to the pathfinder/network routing algorithms. The approach will consider multiple arcs or possibly a gridded structure in the area of interest.

The pathfinder model will determine GO and NOGO areas through an urban environment, incorporating urban restrictions, structural debris, consideration of engineer effort to reshape routes, and incorporation of threat potential. Both the GO and NOGO areas will be determined by the location of structures and buildings and will consider urban terrain attributes such as path width, military load classification of bridges, and other restrictions to vehicle movement. In the GO area predictions, new algorithms will be developed to determine the ability of a vehicle to override non-standard obstacles created from the effects of collateral damage from conventional weapons attack.

This project is a three-year effort with FY02 representing the start. Significant progress has been made and will allow ready improvement in MOUT M&S to be realized and expanded. The development of algorithms for assessing structural damage in urban terrain including the encroachment of structural debris into possible mobility corridors will assist Army M&S in the areas of lethality calculations and in mobility predictions where rubble is created in the urban terrain.

Requirements and Milestones:
Develop algorithms for predicting cratering and generating a crater field - 4Q03
Develop methodology to insert urban templates into COMBATXXI SNE - 4Q03
Produce algorithms for handling overlap of debris and crater fields - 1Q04
Generate and expand urban templates - 2Q04
Develop algorithms for structural damage from internal airblast loadings – 2Q04
Incorporate engineer effort for rubble reduction (task duration,resource requirements) – 2Q04
Develop bypass algorithms for movement on- and off-network - 2Q04
Develop methodology to modify urban terrain network from original data created for urban templates (to account for dynamic changes to the debris field, environmental conditions, etc.) - 2Q04
Construct interface between environment, STNDMob and Pathfinder API expansion - 2Q04
Develop route selection algorithms for dynamic conditions - 2Q04
Expand architecture for calling APIs from COMBATXXI - 2Q04
Dynamic state implementation with ongoing and cumulative effects - 2Q04

Products and Deliverables:
Seven additional urban templates with associated features and attributes
Standard interfaces and algorithms for ready-integration of weapons effects, routing, and vehicle mobility into M&S (SWE API version 2.0; expanded STNDMobility API version 3+;

Network Routing API; Engineer Ops API version 1.0)
Integrated MOUT capabilities implementation in $COMBAT^{XXI}$
Standards submissions for the Army standards program

Points of Contact:
Dr, Niki Goerger, TRAC-Monterey, P.O. Box 8695, Monterey, CA 93943, 831-656-3751 (DSN 756-3751), FAX 831-656-3084, niki.goerger@trac.nps.navy.mil.

MAJ John Willis, TRAC-Monterey, P.O. Box 8695, Monterey, CA 93943, 831-656-7580 (DSN 756-7580), FAX 831-656-3084, john.willis@trac.nps.navy.mil.

Success Criteria:
Success for this project will be defined as the integration of engineering-level models for structural response, mobility, and route planning algorithms through an urban environment replete with impediments to movement processes into $COMBAT^{XXI}$ and reuse for OneSAF Objective System; working routing algorithms that read data for the environment and generate the best path between two points, incorporate obstacles/rubble; and munitions effects algorithms that generate results better than the current state of M&S as "percent damage".

References:
MOUT FACT Research Plan (https://www.moutfact.army.mil)
AMSO Publication (pending)

Status:
This project is ongoing due to late receipt of funds (3Q late). Good progress is being made and milestones have been adjusted. We are making extensive use of AKO Knowledge Center collaboration zone and other tools to promote distributed teaming. Algorithms for predicting cratering and generating a crater field have been developed (4Q03). The methodology to insert urban templates into $COMBAT^{XXI}$ SNE was determined and has been established (4Q03). The network routing API has been delivered to $COMBAT^{XXI}$ and OOS (1Q04). We currently have eight standards submissions in the standard nomination and approval process.

Presentations:
INFORMS National Meeting, San Jose, CA, Nov 02
71st MORSS, Quantico, VA, Jun 03
MOUT Summit III, Aberdeen, MD, Sep 03

Importing Extensible Deformable Structures Into Synthetic Environments

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132, (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
A considerable weakness in current simulations is the ability to accurately model complex terrain and interactions between terrain and entities (such as soldiers, weapon, and vehicles). The objective of this project is to represent complex structures at a resolution conducive to model interactions between complex terrain and entities. This interaction will take the form of firing munitions at a complex structure, thereby causing physics-based effects.

The payoff for this project is a methodology for accurately generating complex terrain for use in modeling military operations. A simulation that accurately models urban environments and entity interactions contributes to success in future conflicts by facilitating better tactics, techniques, and procedures (TTPs), doctrine development, and better weapons analysis for MOUT operations.

The research supports OneSAF's requirement to model urban terrain using the latest technologies. This research also provides potential benefits to legacy simulations and supports standards development in Army standards categories including Computer Generated Forces (CGF), Terrain, and Object management.

Technical Approach:
Two major challenges exist in representing MOUT in distributed military simulations: accurately representing complex structures and accurately modeling entity interactions with complex structures. Our approach is to determine the best methodology to describe and represent structures to enable the representation of physics-based munitions effects in distributed military simulations.

We selected X3D (extensible 3D), an open standard, royalty-free web-based 3D graphics language. X3D is an XML (eXtensible Modeling Language) encoding of the Virtual Reality Modeling Language (VRML), the international standard for 3D graphics on the Web. We will leverage X3D's ability to use metadata tags to develop a schema to encode the characteristics of an Ultra-High Resolution Building for the Army's OneSAF Objective System (OOS) simulation. In addition to the characteristics identified in the OOS Environmental Data Model (EDM), we will add architectural and structural engineering characteristics to facilitate entity interactions such as structural weapons effects. We will propose a format by which all other buildings will be validated against for use by the OneSAF simulation as well as to serve as a means to import/export UHRB models into and out of the OneSAF environmental database.

Requirements and Milestones:
Import an exemplar building based on the UHRB EDM

Develop an XML schema for rendering/storing the UHRB
Represent the X3D translated exemplar building in and open source viewer
Demonstrate physics-based deformations
Demonstrate data transfer of changed structure from X3D back to the OOS EDM

Products and Deliverables:
Updated Deformable Surfaces Technical Report (Sep 03)
Informal technical report describing the OOS EDM integration approach (Sep 03)
Schema of UHRB with EDM and structural/architectural requirements (Nov 03)
Demonstration of damaged UHRB imported back into the OOS EDM (Nov 03)
Technical Report, software source and build files, and design documentation (Nov 03)
Demonstration at I/ITSEC 2003 (Dec 03)
Final Technical Report updated with lessons learned and future direction (Jan 04)

Success Criteria:
The submission of a data standard (schema) for representing an UHRB in OOS by which all other UHRB buildings will be validated against for use in OOS. This schema will also serve as the means to import/export UHRB models into and out of the OneSAF environmental database.

Points Of Contact:
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Dr. Niki Goerger (ERDC Liaison), TRAC-Monterey, P.O. Box 8695, Monterey, CA 93943, 831-656-3751 (DSN 756-3751), FAX 831-656-3084, niki.goerger@trac.nps.navy.mil.

Status:
This follow-on research was funded late in the fiscal year and only preliminary work has been completed. Ongoing work consists of UHRB documentation comparisons, format conversions, structural/architectural characteristic identification, and schema construction. Final products will be delivered after December 2003 I/ITSEC (Interservice/Industry Training, Simulation and Education Conference).

Presentations:
Simulation Interoperability Workshop (SIW), Sep 03
Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), Dec 03

Modeling Target Acquisition, Tracking, and Loss in Urban Terrain with Graphs

Sponsoring Agency:
Army Modeling and Simulation Office (AMSO), Attn: Mr. Dell Lunceford, 1111 Jefferson Davis Hwy Crystal Gateway North, Suite 503E Arlington, VA 22202, (703) 601-0005, wendell.lunceford@hqda.army.mil.

Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132, (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
The outcomes of military operations are highly correlated with target acquisition capabilities. Much of current research in the area of MOUT is focused at the very high resolution level. Some examples of this include:

- Mobility: rubbling, cratering, rubble within craters
- Terrain/environment: effect on communications, impact of "urban canyon" wind on UAV flight
- ISR: distinguishing between a cell phone and a hand gun; LOS determination WRT structural weapons effects and structure characteristics (doors, windows)

There exists a shortfall, however, in Army M&S with respect to lower resolution *aggregate* target acquisition models. While the high resolution entity-level models are certainly necessary for the improvement of Army M&S with respect to urban operations, they are not sufficient. Models that can quickly – and with reasonable accuracy – represent target acquisition for large scale (division and above) urban scenarios are necessary as well.

Technical Approach:
In this ongoing effort, our approach has been to apply mathematical tools, primarily those from the fields of graph theory and probabilistic modeling, in novel ways to suggest aggregate target acquisition models for current and future simulations. In general, we have adopted a methodology similar to the model-test-model approach requiring the following steps:

- Hypothesize a model form
- Conduct high resolution experimentation to estimate model parameters
- Solve the model using parameter estimates
- Validate the model through further high resolution simulation

Specific model forms proposed include Probability of Line-of-Sight (PLOS) models, entity-level target state transition models, aggregate target state flow rate models, and bipartite (sensor-target) graph models.

Requirements and Milestones:
Develop candidate graph models for various aspects of the problem. (4Q03)

Identify graph theoretic approaches that provide insights for candidate graph models. (1Q04)
Develop techniques to analyze the models using random graphs. (2Q04)
Write the technical report. (4Q04)

Products and Deliverables:
Prototype models and/or resultant data tables
Technical report
Presentations and conference papers

Success Criteria:
The project will be complete when the graph models are sufficiently defined to allow for analysis to support Future Force/FCS sensor studies.

Points of Contact:
MAJ Donovan Phillips, TRAC-Monterey, P.O. Box 8695, Monterey, CA 93943, (831) 656-7574 (DSN 756-7574), FAX 831-656-3084, donovan.phillips@trac.nps.navy.mil.

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Status:
This project was originally intended to be a one-year effort, to be completed in FY03. Due to late receipt of funds (3Q03), as well as a desire to leverage the work of recently acquired research partners, we will continue into FY04 and finish in the fourth quarter.

To date, we have developed a Java-based Monte Carlo-type simulation that produces prototype PLOS results for various urban terrain types, observer elevations, and observer-target ranges. The next step for this effort is to determine appropriate functional forms and estimate the associated parameters. Finally, we will validate these models with high resolution simulation.

In addition, we have proposed a family of graphical and probabilistic models that will require further analysis to determine their worth and application. Included are the following:

- Entity level target state models: This family of models depicts targets as existing in one of four states – undetected, detected, recognized, and identified. The next step is to estimate transition probabilities (for time-step simulation) and transition times (for discrete event simulation) between states.
- Aggregate target state flow rate models: Similar to the models described above, these models represent large quantities of targets as being in any one of these states at a given time. Our goal is to estimate the *rates* (as a function of time and other variables) at which targets flow among the various states.
- Bipartite sensor-target graph models: This family of models depicts sensors and targets as nodes on a graph. Arcs (connections between nodes) can represent line of sight between the respective target and sensor or, alternatively, any level of

acquisition of the target by the sensor.

We will continue in our endeavor to discover additional potential modeling approaches while simultaneously furthering the development of those listed above to either demonstrate in principle that they will work or rule them out as viable modeling approaches.

Presentations:
MOUT FACT IPR, Mar 03
Military Operations Research Society Symposium (MORSS), Jun 03
MOUT Summit III, Aug 03

Vulnerability Assessment Methodologies for Water Infrastructure

Sponsoring Agency:
TRADOC Analysis Center (TRAC), Attn: LTC Thomas Cioppa, ATRC-RDM, Monterey, CA 93943, (831) 656-3088, tom.cioppa@trac.nps.navy.mil.

Problem Statement:
The President's Commission on Critical Infrastructure Protection (PCCIP) conducted a study that resulted in the identification of 8 critical infrastructures. The nation's water supply systems are among these critical infrastructures.

Most U.S. water infrastructure systems were developed in a world of relative trust. They were designed to minimize occasional failures from aging and degradation, adverse weather conditions, natural disasters and accidental operator error. Over time these systems have become increasingly complex thereby increasing the potential for these occasional failures that the systems were designed to minimize. In general these systems were not initially designed to withstand sophisticated cyber intrusion or other physical terrorist attacks.

The EPA has issued a vulnerability assessment requirement for all water utilities serving over 3,300 people and has provided $51M to do so. The EPA has not however established a standard vulnerability assessment methodology other than to recommend 17 different agencies that can assist in the training of personnel. One of these agencies, Sandia National Labs, has developed a software package called Risk Assessment Methodology for Water (RAM-W). Unfortunately, the software is only available to relevant stakeholders in the water community and not to the general public. Existing guidance takes the form of checklists and does not take on a holistic, systems approach to risk and vulnerability assessment.

Technical Approach:
The project objectives were:

- To survey the water industry to establish physical and cyber vulnerability assessment techniques currently in use
- To evaluate three emerging vulnerability assessment methodologies
- To develop a recommended vulnerability assessment methodology for the water industry

We created a web-based survey that was distributed to approximately 1,200 members of the water utility and infrastructure control system community. There were 217 responses (~18% response rate. Results of the survey include:

- 64% indicate that they do not have a standard source document or methodology for vulnerability assessments
- 67% feel that current or former employees were the greatest human threat to their systems as well as the most likely threat

- The most frequently cited (43%) component vulnerabilities were elements of networked control systems
- 75% feel the ultimate objective of an attacker is damage to the system
- 46% indicate that denial of service attacks would have the greatest impact on their system
- 24% indicate unauthorized attempts at system access in the past year

The next part of the research focused on the evaluation of 3 methodologies: RAM-W (discussed above), CARVER+Shock, and Infrastructure Risk Assessment Methodology (IRAM).

RAM-W seeks first to identify Design Basis Threats (DBT), representing the maximum credible threat against which a water system's security and operational practices should be designed to defend. Next is a process to characterize facilities, identify redundancy and reliability issues, develop consequence tables, prioritize and weight consequences, and estimate physical protection system effectiveness. RAM-W employs adversary sequence diagrams to conduct threat path analysis. Finally RAM-W allows the user to calculate risk and identify potential improvements to lower risk.

The CARVER+Shock methodology is an inter-disciplinary risk assessment approach used by the military's joint special operations community, law enforcement agencies and some critical infrastructure providers. It is also a methodology of choice for the TRADOC DCSINT Homeland Infrastructure Security and Threats Office (HISTO).

For each component of the system under analysis, CARVER+Shock enables the assessment of:

- Criticality
- Accessibility
- Recuperability
- Vulnerability
- Effect
- Recognizability
- Shock

Following the evaluation of system components, the CARVER+Shock methodology employs a matrix to quantify potential targets. Decision makers can then take appropriate action to mitigate the identified vulnerabilities. An example of a CARVER+Shock matrix is shown in Figure 3.

Target	C	A	R	V	E	R	Shock	Total
Intake Pump Station	7	3	6	2	3	9	6	35
Pump System	9	3	8	1	9	9	6	45
Source	5	4	4	3	3	9	6	34
Water Transfer	5	8	3	8	5	8	3	42
Mains	6	9	7	9	5	8	3	47
Backflow Valves	3	6	3	4	3	8	3	30
Water Treatment	9	9	9	10	9	10	8	64
Chemical Treatment	8	10	9	10	9	9	8	63
Control Center	10	8	10	9	9	10	8	64
Monitor/Control Center	9	7	9	9	10	5	9	58
SCADA/Switches	9	7	3	8	10	8	10	55
Computer Hardware	9	8	10	9	9	10	9	64

Figure 3: Example CARVER+Shock Matrix

The final methodology we examined was the Infrastructure Risk Assessment Methodology (IRAM). IRAM is a probabilistic risk assessment and decision-making process designed to assess and manage the risks of willful threats to critical infrastructure. The 4 steps of the IRAM framework are shown in Figure 4 below.

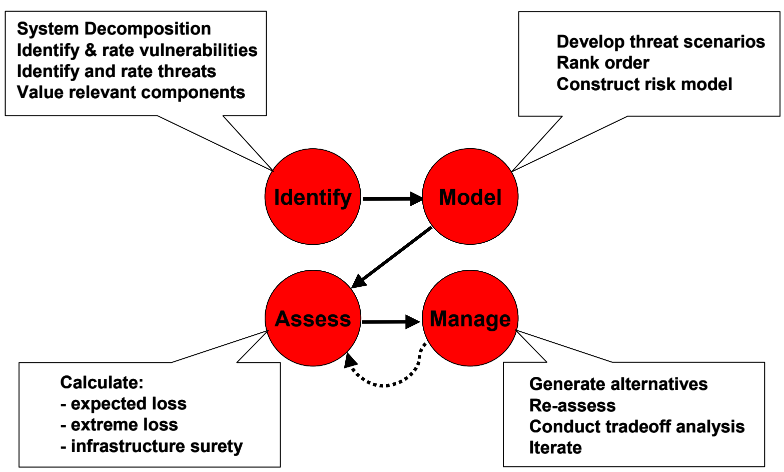

Figure 4: IRAM Framework

In the first step, system decomposition examines the entire system in a holistic manner and breaks it down into its functions, components, structure, and states. Vulnerabilities, threats and system components are identified and prioritized. Next, threat scenarios are developed and ranked and a risk model is constructed. Then, probabilistic losses are calculated for expected and extreme events. Alternatives are generated, trade-off analysis is conducted and assessments performed on each of the alternatives. Simulation can be used as a tool for running threat scenarios and testing alternative solutions. The dashed arrow indicates that the process is iterative.

Our research shows that the water industry recognizes the threats of cyber and physical attacks against its infrastructure. We recommend that the EPA/DOE standardize and mandate the use of a risk assessment methodology for the water industry. Additionally, given the wide variety of techniques currently in use from simple checklists to advanced decision tools, we recommend that the standardized methodology selected be IRAM or a similar quantitative systems-based assessment and management technique.

Requirements and Milestones:
Survey creation/distribution (2Q03)
Survey analysis (3Q03)
Vulnerability assessment methodology analysis (3Q03)
Results synthesis and recommendation (4Q03)

Products and Deliverables:
Web-based water/SCADA industry survey
Vulnerability assessment methodology analysis

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Success Criteria:
The first element defining success for this project is the distribution of the web-based survey and collection of relevant and statistically viable data for analysis. Second is the analysis of existing vulnerability assessment methodologies in practice to determine a technique most appropriate for use by the water infrastructure community. Finally is the development of recommendations for implementation by the water infrastructure community and the EPA/DOE.

Status:

All milestones were met and all deliverables were completed IAW the project plan. A technical report entitled "Vulnerability Assessment Methodologies for Water Supply Infrastructure" (TRAC-TR-04-003) was published in October 2003.

Presentations:
US/Canadian Operations Research Symposium, Ft. Monroe, VA
Army Conference on Applied Statistics, Napa, CA

Elements of Combat Power

Sensor Mix Model

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132, (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
The Future Force Unit of Action's (UA's) effectiveness and performance relies on a pervasive, robust C4ISR network that provides a Common Relevant Operating Picture (CROP) to most platforms. Without a robust C4ISR network, Future Combat System (FCS) lethality, survivability and mobility will decrease or may be significantly degraded[1]. Manned and unmanned aerial, vehicle-mounted, and ground sensors are essential components of the C4ISR network. Given the existence of various (often competing) factors such as available sensor types, target types and densities, terrain, and sensor characteristics (cost, latency, survivability, logistical requirements, etc.), a quantitative method for determining the optimal sensor mix that allows the UA to detect, recognize and identify the Contemporary Operating Environment threat – while accounting for uncertainties in sensor performance and threat array – is required.

There are two aspects to this requirement: operational and M&S. The operational aspect addresses the need for a tool to assist decision makers with such issues as: force structure (how many/what types of sensors should be organic to the UA?); mission planning (what sensor array should the UA be equipped with for a specific mission); mission execution (how should a given sensor array be employed?); and risk assessment (what risk is associated with deploying a UA with a sub-optimal sensor suite?). The M&S aspect addresses the need for a methodology for rendering such operational phenomena in existing and future models and simulations. Of all FCS sensors currently being considered, *which* should be employed in a given scenario? *How many* of each should be employed, and *how* should they be employed? The goal of this project is to determine the optimal sensor mix that allows the UA to detect, recognize, identify and track the Contemporary Operating Environment Threat.

Technical Approach:
This project will be conducted in two phases:

Phase I will involve modification of an existing mathematical programming model (developed by TRAC-FLVN) to more closely track sensors and their possible deployment in a scenario. These modifications will include:

1) The addition of a grid reference system to allow sensor missions to be assigned to specific locations in the AO. Currently, sensor missions are evaluated over all possible range bands

[1] FCS Unit of Action Systems Book, AMSAA Version 1.2, July 2002

to which they could reasonably be assigned. Targets are allocated to range bands, but not given any locations on the map.

2) The explicit inclusion of random outcomes in sensor performance, target location, and target density, so as to encourage the use of a more robust mix of sensors for a given scenario.

3) Various model enhancements/corrections including accounting for over/under detections and modifying the objective function.

Phase II will involve a Masters student at NPS, and will result in a thesis for that student. It is based on modeling a time-phased deployment of sensors into specific grid locations in the AO. This may require the development of a new model that extends the decisions made in the Phase I model (how many of each type of sensor to put in each grid location) to include a time component (how many of each type of sensor to deploy to each grid location, in each time period). The constraints of this model will be much more complex than in Phase I, as the problem takes on a scheduling character, as opposed to the assignment character of Phase I. Primary activities in this phase will include:

1) Development of basic Phase II modeling approach. This model will have aspects of vehicle routing (especially for UAVs and other long range, highly mobile sensors), scheduling (limited resources have to cover a time-varying workload), and assignment (sensors will be allocated to specific locations in specific time periods).

2) Integrating Phase I model with Phase II model. This will involve two main steps: using Phase I solution/output as input to Phase II; and using results from Phase II to modify the solution to Phase I.

Requirements and Milestones:
Elimination of the concept of "retask time" for Phase I model (1Q03)
Penalization of over-detection (1Q03)
The addition of a grid reference system to allow sensor missions to be assigned to specific locations in the AO (1Q03)
Creation of unclassified test data for model development/testing (1Q03)
Review of objective function (goals, weights, etc.) (2Q03)
The explicit inclusion (in the optimization) of random outcomes in sensor performance (2Q03)
Prepare report on Phase I model (2Q03)
Development of time-phased sensor deployment model (3Q03)
Integration of Phase II model with Phase I model (4Q03)
Testing, modification, and results analysis (4Q03)
Prepare report for Phase II (4Q03)

Products and Deliverables:
A mathematical programming model and supporting code (Phase I in the GAMS modeling language, Phase II in GAMS or another appropriate system), including appropriate (unclassified) test data to demonstrate functionality.

Sufficient documentation to enable future users to develop their own data and adapt the model to different scenarios.

Success Criteria:
Success is contingent upon the ability of resultant model(s) to efficiently and effectively determine optimal or near-optimal initial sensor arrays for the UA, as well as optimal employment strategies for this sensor array. Additionally, these models will have the capability to interface with other tools/models as appropriate.

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Status:
All requirements and milestones have been accomplished. Report can be viewed at http://library.nps.navy.mil/uhtbin/hyperion-image/03Jun%5FTutton.pdf. In addition, we have made significant progress toward the integration of the Sensor Mix Model with DAFS (Dynamic Allocation of Fires and Sensors), an emerging Java-based simulation developed at TRAC-Monterey. In combination, these tools will be capable of supporting studies and analyses such as NLOS Mix Study and the FCS KPP analysis.

Presentations:
Mr. Walt Hollis, Dec 02
Military Operations Research Society Symposium (MORSS), Jun 03
MORS-Tisdale Competition, Jun 03

Human Factors Analysis in a C4ISR Experiment

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: Ms. Blechinger, Fort Leavenworth, KS 66027, 913-684-9121, (DSN 552-9121), blechingp@trac.army.mil.

Problem Statement:
Human factors analysis is critical for FCS and Future Force command and control systems and decision support tools. Requirements for lengthy tactical commitments (72 hours) and situational understanding dictate the need to study the effects of the future forces on leader and staff personnel. The C4ISR experiment being conducted by TRAC and the Unit of Action Maneuver Battle Lab (UAMBL) affords the opportunity to study two critical categories of human factors: workload and situational awareness.

A Common Relevant Operating Picture allows shared awareness on the battlefield, but its utility is dictated by the quality and quantity of information presented, the amount and details of battlespace information of which the individuals can be cognizant, and the environment in which they operate.

Technical Approach:
This project consists of three phases. The first phase includes a literature review and selection of performance models to be used during the evaluation phase. Phase two will be training of data collectors, data collection during the experiment, and preliminary analysis and insights. Phase three includes more detailed analysis and documentation of the findings.

Requirements and Milestones:
Assist Human Factors Lead (ARL) in test design and data collection plan for the FCS C4ISR Experiment. (1Q03)
Provide referenced research to Human Factors Lead and Study Director (1Q03)
Assist with data collection and analysis (1Q03)
Provide final report input to the study director summarizing human factors analysis (2Q03)

Products and Deliverables:
Observer forms for situational awareness and workload assessments
Team mental model
Initial insights
Input to the C4ISR Experiment Final Report

Success Criteria:
The FCS C4ISR experiment will provide Milestone B insights. The human factors insights gained from this experiment will be included in the final report. Follow on study requirements will be identified from this study.

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Status:
This project is complete and all milestones and deliverables were achieved. The C4ISR experiment and the Human Factors analysis that supported the experiment were a qualified success. Techniques and procedures for measuring situational awareness for a future force will evolve based on the work of this project. Additionally, two researchers from USMA and Naval Postgraduate School who formed a partnership as a result of this study are working on expanding this methodology in upcoming experiments.

Presentations
Findings were included in the C4ISR Experiment Report and briefs presented by TRAC-FLVN.

Information Measures of Effectiveness

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132 (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
Analysis for the Future Force requires the ability to judge the contributions of information to the overall force effectiveness of the units. The underlying paradigm of network-centric warfare puts a premium on the value of information. Requirements documents for the Future Force state that the cumulative effectiveness of these units is a sum of maneuver, firepower, protection, and leadership raised exponentially to the value of information.

Despite widely held beliefs that information significantly enables a unit's performance, little information is available that actually proves such is the case. Technological challenges will potentially prevent instantaneous promulgation of perfect, fused, and correlated information. Figuring out how much information is enough, judged by qualities of the information, is key to transformation analysis.

Technical Approach:
This project will satisfy a Naval Postgraduate School thesis requirement while providing key insights for the Future Combat System (FCS) analysis of alternatives. Using a simulation-building toolkit, the study team will develop a FCS scenario with assigned sensors using beyond-line-of-site engagement tactics to acquire and destroy threat forces. Information on threat forces is hindered by the presence of previously killed vehicles and decoys.

The independent variables will include the amount of information gathered and an aggregate process, analysis, and transmission value. By changing the levels of these values, which will mirror changes in information qualities such as consistency, accuracy, and latency, insights will emerge as to the value of information. The dependent variable will be the number of rounds required to destroy threat forces.

Requirements and Milestones:
Build model using above described scenario (2Q03)
Conduct runs and analyze data (3Q03)
Provide thesis as written report (3Q03)

Products and Deliverables:
Approved thesis

Success Criteria:
This is one of the few projects that look directly at information gain as a measure of a unit's efficiency. Explicit representation of all the factors associated with network-centric ground combat is beyond the reach of current technologies, so incremental approaches to understanding the value of information is key to understanding the ramifications of

transformation. Success is contingent upon meaningful correlations between the quality of information and force efficiency, if such correlations even exist.

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Status:

This project is complete and the findings are included in MAJ Joseph Baird's June 2003 thesis *Measuring Information Gain in the Objective Force* (http://library.nps.navy.mil/uhtbin/hyperion-image/03Jun_Baird.pdf). The project also resulted in the development of a simulation, "MCS Killing Machine," that may be a useful tool for information and sensor based parametric analyses. The main finding of his study is that small errors in the quality of information lead to inefficiencies in accomplishing the mission. Proposed organic ISR capabilities at the company-equivalent level will most likely not allow situational awareness throughout the range of the battlespace. The simulation is available to users interested in continuing this research.

Presentations

MORSS, Jun 03
AORS, Oct 03

Networked Fires

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132, (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
This research directly supports the development of models and simulations for the US Army Future Force. It will expand the way in which the Future Force and Future Combat System (FCS) are modeled. Dynamic Allocation of Fires and Sensors (DAFS) is meant to become an analytic and screening tool for the development of future army doctrine and related models and simulations. This project will develop algorithms that determine the best way to allocate fires and sensors for a Future Army Force. This effort will lend insights into organizational and operational concepts for the Future Force and will assist in future Army simulations such as Combat ^{XXI} and OneSAF.

Technical Approach:
Our approach involves the following tasks: continue the integration of the Sensor Mix Model into DAFS for initial allocation of RSTA Sensors; expand data management capabilities to enable parallel runs with higher resolution models; and conduct verification, validation and accreditation (VV&A) of DAFS.

Requirements and Milestones:
Support the NLOS Weapons Mix Study by conducting parallel runs with RAND model (2Q03)
Provide analysis of results to TRAC (2Q03)
Conduct VV&A of DAFS and publish results in a usable format (3Q03)

Products and Deliverables:
NLOS Weapons Mix Study Results and Analysis were delivered to TRAC to support the ongoing study sponsored by the Futures Division of the Fort Sill Battle Lab. Capt Kevin McMindes consolidated complete VV&A report at TRAC Monterey and is being used by the simulation developers to further improve the model in execution and usability.

Success Criteria:
The end state is developing an analytical and screening tool for not only developing doctrine but also for screening and paralleling high resolution models, specifically:

DAFS is accepted as an abstract simulation that can portray sensors, FCS platforms, enemy targets and the interaction among them. It will be a framework to experiment with different methodologies and algorithms to assign and allocate sensors and fires. It will also portray the risks and implications by adjudicating sensor pickups, simple outcomes of fires, and blue and red losses. It will model the common operating picture (COP) through the simulation of time steps and a BDA process.

DAFS will be a test bed for adjusting various input factors and measuring responses relevant to FCS and Future Force studies. It has the ability to provide much quicker precursory runs to indicate where runs should be completed in high resolution models. It has the potential to test new tactics, techniques and procedures for the FCS platforms through the use of individual mover managers. It has the ability to perform logistics measurements on platforms as well as munitions.

Status:
In addition to the aforementioned accomplishments, TRAC-Monterey submitted DAFS to the C4ISR FACT and was recommended favorably for funding. The stated goals of that proposal are summarized below:

1) VV&A effort of existing simulation:

2) Integrate existing Sensor Mix Model as the methodology of assigning sensors packages to

3) Develop a line of experiments related to Sensor and Fires assignment and Combat Assessment using the DAFS Simulation.

More information can be found in the TRAC-Monterey Research Plan for FY04.

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Presentations:
AORS, OCT 02
MORS, JUN 02

Advancements in Simulation

Modeling Natural Decision Making (NDM) for Information Fusion and Military Decision Making (NDM4Fusion)

Sponsoring Agency:
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Problem Statement:
It is difficult to measure the value of information and the effectiveness of fusion algorithms. However, Future Force decision makers must act swiftly and decisively using fused information presented in a common relevant operating picture. Increased reliance on information requires that we model human decision making processes better to support planning and course of action analysis.

A commander will need to assess the trustworthiness of his information, possibly as a subjective measure of the quality of his data, before he uses that data to make decisions. Potentially, commanders with imperfect information will make the correct decisions, make hasty, but bad decisions, or be paralyzed with indecision as a result of incorrect quantities or qualities of data.

Modeling these interactions between information and the users of the information is critical to understanding the information-centric paradigm of the Future Force. Decision support systems, leader development curricula, and joint force plans all require understanding of how humans interact with information and make decisions in a mission context.

Natural decision making (NDM) strategies incorporate intuition and are based on observation of human decision making in the real world while accomplishing real tasks. They compliment the deliberate, rational decision making approach used in the military decision making process (MDMP) and have strong application to the evolving decision environment of the Army's Future Force. NDM models are needed that: model human decision processes; incorporate education, training and experience; are traceable; adapt and learn; work in uncertain & dynamic environments; and can be supported with knowledge acquisition and data.

Technical Approach:
This project will develop and prototype a natural decision making behavior model to support evaluation of information fusion algorithms and to measure the value of information. This behavior model will support replication, experimentation and simulation of military decision-making processes. This research will produce a framework to evaluate decision-making based on a common operating picture.

Our preliminary research has identified three potential related models: Recognition-Primed

Decision Making, Singular Evaluation, and Nonlinear Problem Solving. These models share certain internal representations as well as certain algorithms like recognition and mental simulation.

Knowledge acquisition is critical for behavior modeling. Cognitive task analysis is a set of interviewing, observation and analysis techniques aimed at understanding what goes on inside people's heads as they interact with their world. It unpacks expertise and describes cognitive processes in the context of a task. Cognitive task analysis supports NDM by providing a proven approach to knowledge acquisition for NDM behavior models.

The first phase of the project includes further background research and additional work developing natural decision models for military modeling and simulation. This potentially includes developing model details, representations, data representations, and supporting algorithms.

Phase two will involve implementing a natural decision model prototype and conducting a proof of principle demonstration. The research team will implement the model and fully document both the model and the implementation. The research team will also document data requirements and provide guidance to military subject matter experts to assist in future knowledge acquisition and behavior development.

Requirements and Milestones:
Preliminary Research (1Q03)
Use Case Development (1Q03)
Model Development (2Q03)
Model Implementation (2Q03)
Proof of Principle Demonstration (3Q03)

Deliverables:
Natural Decision Making Model
Prototype implementation to support experimentation and further research
Proof of principle demonstration

Point of Contact:
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Status:
We have proposed and described three related Naturalistic Decision Models using common components. The first model, Recognition Primed Decision-making (RPD) was prototyped as a Bayesian Net/Influence Diagram in a commercial off the shelf product, Netica. This general model is a template for a series of situation specific models. We briefed the RPD model extensively to researchers in the field, military simulation developers, and military decision makers. The consensus recommendation from these experts was that data development was critical. Therefore, we partnered with TRAC-WSMR to leverage their

recent experience gaming the new FCS. They have developed decision vignettes that we will use to collect data and refine specific models to further demonstrate the concept.

Presentations:
BCBL-FLVN
ARL ADA CTA
PM OneSAF & TPO OneSAF
TRAC-WSMR Combat^{XXI} Development Team
TRAC-WSMR Training

Agent Based Modeling

Sponsoring Agency:
US Army TRADOC Analysis Center Monterey (TRAC-Monterey), ATTN: Lloyd P. Brown, Major USMC, Marine Corps Representative, Monterey CA, 93943, 831-656-7578 (DSN 756-7578), Lloyd.Brown@trac.nps.navy.mil.

Problem Statement:
Agent based simulations (ABSs) have attracted considerable attention recently, but little is understood about this emerging modeling methodology, and the utility of this approach for future Army M&S is not known. The fundamental question this experiment is attempting to answer is: are agent based simulations appropriate for use in supporting Future Force and FCS analysis?

The relative simplicity of current ABSs offers two key advantages. They are quick to set up and they run very fast. From the time a simple scenario is conceived, it may take less than a week for a single analyst to implement the scenario and conduct tens of thousands of simulation runs. This compares to the more traditional constructive military simulations that may take many months to implement and produce only a few runs.

The ability to produce tens of thousands of simulation runs allows the analyst the ability to consider thousands of alternatives. This ability generates many data points, and, coupled with recent advancements in experimental designs, allows the analyst to explore many dimensions of the models' input space and identify critical variables, important interactions, and the ranges of the affected variables. This means of exploratory analysis has the potential to provide effective analytical support to the larger traditional constructive simulations.

Technical Approach:
The approach in this experiment was to develop an urban scenario with guidance from the Dismounted Battlespace Battle Lab (DBBL), Ft Benning, and to conduct trade-off analysis across two agent based simulations and a high resolution simulation to determine the appropriateness of these models for Future Force/FCS analytical support.

Specifically the experiment used a series of new models and analytical tools developed under Marine Corps Warfighting Lab's (MCWL) Project Albert to explore questions relative to the Future Force in an urban environment. The particular simulations used were Pythagoras, MANA and JANUS. We exploited recent advances in computing power by utilizing the Maui High Performance Computer Center (MHPCC) to implement our design of experiments and conduct thousands of runs to explore questions from the perspective of many data points.

The scenario focus was on a Future Force infantry platoon with an Armed Robotic Vehicle (ARV) against an organized threat in an urban environment. The scenario was set up with blue forces moving through an urban environment to an objective. The scenario had aggressive red forces that continually patrolled the environment. The experiment conducted trade-off analysis on squad size (7, 9, 12), the number of squads (2, 3, 4), the weapons mix in squads, the use of an FCS vehicle and the weapon and sensor mix on the FCS vehicle.

The urban scenario was migrated across the two ABS, MANA and Pythagoras, and then to the high resolution simulation, JANUS. The scenario was migrated as consistently as possible across all three simulations. There were some minor differences in the underlying assumptions of the simulations that required minor deviations. However, every effort was made to keep the scenario as consistent as possible throughout the migration process.

The experimental designs chosen for this experiment are relatively new and were developed to improve on the ability to efficiently explore the larger subspaces of the simulation models. These new designs essentially combine orthogonal Latin Hypercubes and uniform designs to create designs having near orthogonality with excellent space-filling properties. A more thorough and technically complete discussion on the new experimental designs can be referenced in Cioppa (2003).

There were two different experimental designs chosen for this experiment. The two ABS, MANA and Pythagoras, provided the ability to conduct many simulation runs through the use of the MHPCC. The experimental designs used were a 16 variable, 65 run design with 50 replications per run for a total of 3250 simulation runs. The significant factors and interactions of interest were identified and then a subset of the factors was chosen for further exploration in the high resolution simulation JANUS. The experimental design used for the JANUS runs was a 7 variable, 17 run design with 10 replications per simulation run. Just over 10,000 simulation runs were executed for the experiment.

Requirements and Milestones:
Prepared designs and Scenarios for ABS Runs (1Q03)
Conducted Simulation Runs (2Q03)
Completed Analysis and Report (3Q03)
Briefed Outcome (4Q03)

Products/Deliverables:
Technical Report TRAC-M-TR-03-02, June 03. (3Q03)

Success Criteria:
This experiment provided a reference on the usefulness of ABS to support Army M&S. It incorporated the use of new analytic tools and experimental designs to strengthen the exploratory analysis methodology that can be utilized to support the high resolution constructive M&S environment.

Status:
The tools and experimental designs utilized in this experiment have been provided to DBBL. The exploratory analysis methodology developed during this experiment has received a positive response from senior Army decision makers. The methodology developed during this experiment is being utilized to support the current on-going post milestone B FCS

Analysis.

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Presentations:
MORS, June 2003
DBBLE, Ft Benning, Aug 2003
AORS, Oct 2003
ACAS, Oct 2003

Advancements in Experimental Designs

Sponsoring Agency:
Headquarters, US Army TRADOC Analysis Center (TRAC), ATTN: ATRC (Mr. Bauman), Fort Leavenworth, KS 66027, 913-684-5132 (DSN 552-5132), baumanm@trac.army.mil.

Problem Statement:
The Department of Defense (DoD) uses simulation models to support its decision-making process by, among other things, testing war plans, deciding what equipment to acquire, determining the best combination of forces, and determining the best combination and use of weapons. Since it is nearly impossible to conduct actual physical experiments to determine the effectiveness of war plans, force designs, or weapon system capabilities in actual conflict, the DoD relies on these simulation models to capture significant insights that enable senior leadership to make informed decisions.

A new and stimulating area of combat models involves complex adaptive systems. The concept is to use multi-agent-based software tools to examine the relationship between numerous input variables and output measures. The self-adaptive nature of these models facilitates broad exploration and permits the possibility of gaining substantial insights into emergent behaviors on the battlefield (Horne and Leonardi [2001]). The major proponent of this current research is the Marine Corps Combat Development Command's Project Albert.

A common characteristic of the above-mentioned models is the vast number (sometimes even greater than 100,000) of variables or data elements present—many of which are uncertain. Conducting a comprehensive experimental design on these numerous variables is prohibitive. Often, a small subset of the variables (usually no more than two or three) is chosen for experimentation. In such a case, the results are necessarily assumed to be invariant to the large number of uncertain variables held constant, but no empirical assessment is made. In addition, even a small, manageable subset does not guarantee that a detailed experimental design will be used. The problem is compounded since, even if a manageable subset of input variables is chosen, determining the appropriate levels or settings of the variables remains an issue. Remembering that the main thrust of the experimentation is to identify significant insights, this goal may be jeopardized when a small subset of variables or inappropriate levels of the variables are used.

Defense analysts need experimental designs capable of efficiently searching an intricate simulation model that has a high-dimensional input space, characterized by a complicated response surface (substantial non-linearities may be prevalent). The experimental designs to be developed can provide the ability to search a comparatively high-dimensional (up to 22 variables) subspace of a simulation model and reliably identify critical variables, important interactions, and the ranges of the variables where these effects occur. Furthermore, the number of runs required is small (e.g., a minimum of 129 runs for 22 variables) when compared to most existing experimental designs.

Technical Approach:
This work will develop experimental designs that provide the ability to search a high-dimensional (up to 22 variables) simulation model and reliably identify critical variables, important interactions, and the ranges of the variables where these effects occur.

The two most important characteristics for these designs are orthogonality and space-filling. Two measures are used to assess the orthogonality of a design matrix: the maximum pairwise correlation and singular value decomposition condition number. The use of both measures provides a better ability to differentiate between the orthogonality of candidate designs.

Number of experiments	Number of variables examined in the orthogonal or nearly orthogonal designs	Number of variables examined in previous orthogonal designs	Percent increase in number of variables examined
17	7	6	17%
33	11	8	38%
65	16	10	60%
129	22	12	83%

Table 1. The designs developed in this work will be able to examine a greater number of variables than similar previous designs in the same number of runs. These new designs still have excellent orthogonality and space-filling characteristics. The algorithm generalizes for an arbitrary number of variables.

Requirements and Milestones:
Prepare designs for Agent-Based Model Runs. (1Q03)
Prepare refereed journal article for submission to *Technometrics*. (3Q03)
Investigate inclusion of factors or variables having a fewer number of levels than required runs. (4Q03)

Products/Deliverables:
Provided designs for Agent-Based Model Runs.
Prepared journal article for *Technometrics*.
Provided designs for AMSAA's Future Combat System (FCS) analysis.

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Success Criteria:
Establish a framework such that experimental designs are successfully integrated into military analytical work using simulations. This is accomplished by using these new designs in emerging simulations and illustrating their potential. The key elements are to ensure that the context of the specific problem is understood, what factors or variables require examination, and their requisite number of levels. The design is then tailored to meet the

needs of the analyst instead of vice versa where the analyst must take a specified design.

Status:
These new designs were used in the Future Force Urban Experiment in support of the US Army Dismounted Battlespace Battle Lab. Subsequently these designs are being developed in support of the FCS Key Performance Parameter analysis. In conjunction with Professor Tom Lucas of the Naval Postgraduate School, new designs were developed for AMSAA to assist in their FCS System-of-Systems Supportability study. Work will continue in FY04 to assist TRAC-WSMR in their STAMP Phase II analysis.

Presentations:
AORS XLI (October 2003)
Army Conference on Applied Statistics (October 2003)

XML Characteristics & Performance Data Interchange Format Standard for Army Simulations (XML C&P DIF)

Sponsoring Agency:

Director, Army Modeling & Simulation Office (AMSO), Data Standards Category, ATTN: Mr. Jin Kwon, Data Standards Category Coordinator, Army Material Systems Analysis Activity (AMSAA), Aberdeen Proving Ground, MD 21005, (410) 278-2787, (DSN: 298-2787), Kwon@AMSAA.army.mil.

Problem Statement:

Data providers currently export data in formats native to them rather than the consumers or are forced to export data in multiple formats tailored to specific simulation applications. By providing data in a standard format, each provider requires only one set of routines to provide an external view of the data regardless of the user, and each user requires only one set of routines to import the data. Providing characteristic and performance (C&P) data to users in a common format supports automated delivery of data to all M&S domains as well as to other consumers of C&P data.

Authoritative data providers (e.g., AMSAA and NGIC) currently provide equipment C&P data to modeling and simulation customers in various formats and by various means. The use of proprietary formats for interchanging data between data producers and consumers results in extensive data manipulation and delays in the application of the data. Equipment C&P Data Interchange Format (DIF) standards are needed to address these challenges.

Technical Approach:

At the end of the first year a limited scope of vehicles and associated direct fire weapons was supported. By the end of the current second phase, the Data Standard will encompass sensors, indirect fire systems, army aircraft and communication systems. Initial funding was used to study the data requirements of sample consumers, identify the data available from sample producers, develop a DIF to facilitate the sharing of information, and demonstrate the use of the DIF. Researchers defined the data requirements of three consuming simulation development efforts: OneSAF Testbed (OTB), COMBAT ^{XXI} and OneSAF Objective System (OOS). The associated data supplied by AMSAA and NGIC was identified and current formats were documented. A DIF was developed and formalized using an XML DTD and XML Schema.

Sample data provided by AMSAA and NGIC is being provided according to the DIF for use in a demonstration involving OTB, COMBAT ^{XXI} and OOS file formats. The effort has received involvement by a TRAC-Monterey led team of researchers representing AMSAA, NGIC, COMBAT ^{XXI}, and STRICOM. Additional equipment types (e.g., communications equipment, sensors) will be included to provide more value to producers and consumers of equipment data. Additional consumers should be supported with continued funding.

Requirements and Milestones:
Develop a companion-coding standard for consistent naming of interchanged data (2Q02)
Determine OneSAF Object System data requirements (2Q02)
Document the developed standards, recommended methodology, and metrics (4Q02)
Submit XML C&P data standards into the SNAP/ASTARS process (4Q02)
Deliver Expanded DIF database (4Q02)

Products and Deliverables:
Consumer Requirements Document, to include OneSAF Objective System
Producer Inventory Document
Companion Coding Standard Document
DIF Design Document to include the expanded database
Demonstrate the translation of the data into formats required by COMBAT ^{XXI} and OTB
Demonstrate access to the expanded database using XML, COMBAT ^{XXI} and OneSAF Testbed applications

Success Criteria:
Successfully expand equipment types supported by DIF to increase support for OneSAF Testbed and COMBAT ^{XXI} requirements. Promote data sharing and reuse across simulations and their supporting applications. Reduce requirements for custom code needed for data import and export. Accommodate changes to both producer and user databases without additional costs.

Status:
Indirect fire systems, sensors, army aircraft and communications systems are now supported with an XML DIF for the three target models (OneSAF, CombatXXI and OTB). The Data Interchange Format was demonstrated with AAMSA Sensor data for future systems, though it is currently immature with respect to the Future Force design and cannot be fully represented. The DIF can be developed without the data, however.

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